conditioning unit led to rejection of a number of runs while the experiment was in progress. Since there is a possibility that in some cases the erratic behavior was not immediately recognized, no significance should be attached to the behavior of the Ni^{60} curve near 100°.

The energy resolution of the detection system was about 2%. All deuterons scattered from levels more than 1 Mev above the ground state were clearly distinguished as not belonging to the elastic peak. The particle separation was similar to that previously obtained.[5,8]

III. EXPERIMENTAL RESULTS

The results are shown in Fig. 1.[9] The angle is given in the center-of-mass system and the numbers given are the relative differential cross sections in the center-of-mass system multiplied by $\sin^4(\theta/2)$, where θ is the center-of-mass angle. The data were normalized to facilitate comparison, since the targets did not have the same thickness and it was not possible to measure the foils without destroying them. The data were normalized by assuming that the sum of the values of σ/σ_R from 18° to 34° should be about equal. In the case of Ni^{60} the normalization was carried out by equalizing the sum of σ/σ_R from 41° to 60° to that of Ni^{58}. Since the differences in the angular distribution, as plotted in Fig. 1, are small, it was desirable to obtain some measure of the internal consistency of the data. The standard deviation in the number of counts in the elastic peak between 80° and 18° was less than 2%; and between 80° and 117.5° it was generally less than 4%. It would appear, therefore, that a plot of $\sigma/\sigma_R-\sigma'/\sigma_R'$ should give a reliable measure of the internal consistency and of the magnitude of the shift between neighboring masses. Figure 2 shows the results of these plots for Ni^{58} and Ni^{60}, Ni^{60} and Cu^{63}, and for Cu^{63} and Cu^{65} together with the standard deviations at some of the points. From this one may conclude that the shift between Ni^{58} and Ni^{60} is the same as that between Cu^{63} and Cu^{65} and about $\frac{2}{3}$ of that between Ni^{60} and Cu^{63}. It may be noted that the difference plot between Cu^{63} and Cu^{65} shows a consistent average slope. This cannot be due to the normalization procedure. It is also to be noted that even as far forward as 18° there is a noticeable difference between the cross sections for Cu^{63} and Cu^{65}.

[8] J. L. Yntema and B. Zeidman, this issue [Phys. Rev. **114**, 815 (1959)].

[9] The tabulated angles and cross sections are contained in J. L. Yntema, Argonne National Laboratory Report ANL-5936 (unpublished); available upon request.

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Search for the Isotope Ir^{196}†

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The isotope Ir^{196} has been reported to have a half-life of ~9 days and to emit β^- particles with a maximum energy of about 0.08 Mev. Using deuteron-bombarded enriched isotopes of platinum, it is shown that the previous mass assignment was incorrect. It is suggested that the ~9-day activity found in deuteron bombardments of natural platinum is due to Ir^{189} and Ir^{190} produced by the (d,n) reaction on osmium impurities. An experimental upper limit of 5 hours for the Ir^{196} half-life can be set by these experiments. Rough cross sections for the (d,α) reaction on Pt^{194} and Pt^{196} are given for several deuteron energies from 9.6 to 20.4 Mev.

I. INTRODUCTION

BY 1953 an isotope of iridium, Ir^{196}, was listed in isotope tables as having a half-life of ~9 days and decaying by the emission of an ~0.08-Mev β ray. A half-life of that order was surprising since Ir^{194} has a half-life of only 19 hours. Furthermore, the half-life and β-ray energy indicated that the transition was allowed, an unlikely occurence for this section of the isotopic table. In 1954 Butement and Poe,[1] who had contributed the original information on this isotope, published further information substantiating their previous findings and listed γ rays at energies of 0.58, 0.76, and ~1.0 Mev. A search of the literature and isotope compilations[2,3] through September, 1958 has revealed no further work on this isotope.

II. EXPERIMENTAL PROCEDURE

The radioactive iridium was produced by the (d,α) reaction from deuteron bombardment of metallic

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[1] F. D. S. Butement and A. J. Poe, Phil. Mag. **45**, 31 (1954).

[2] Strominger, Hollander, and Seaborg, Revs. Modern Phys. **30**, 585 (1958).

[3] K. Way *et al.*, *Nuclear Data Cards* (National Research Council, Washington, D. C., 1958).

platinum. Therefore, a chemical separation was needed to obtain the iridium free from contamination by platinum and gold activities produced by (d,p) and (d,n) reactions on the platinum target, and also from activities produced by reactions on the impurity elements.

After bombardment the platinum target was dissolved in boiling aqua regia, and 3 mg of iridium carrier as well as 10 mg each of copper, nickel, zinc, and gold carriers were added. After evaporation, the solution was made $\sim 0.5N$ in HCl and gold was removed by extraction with ethyl acetate. Pt(IV) was reduced to Pt(II) with $SnCl_2$ and then removed by extraction with ethyl acetate. The solution was next evaporated to dryness with aqua regia, and 5 mg of inactive platinum carrier added. After removal of NO_3^- the solution was made $\sim 0.5N$ in HCl and saturated with NH_4Cl, precipitating $(NH_4)_2PtCl_6$ and $(NH_4)_2IrCl_6$. The precipitate was dissolved, NH_4^+ removed, and IrO_2 precipitated with NaOBr. After washing, the precipitate was dissolved in HBr and the iridium mounted as the bromide by evaporation onto $\frac{1}{4}$-mil Teflon films.

Both natural and isotopically enriched platinum metal targets were used. The natural platinum was 1.05-mil thick "commercial grade" foil, 99.5% pure, obtained from Baker and Company, Inc., Newark, New Jersey. No numerical estimates of the impurities were available. The enriched material was obtained from the Isotope Research and Production Division, Union Carbide and Carbon Chemicals Company, Oak Ridge, Tennessee. In this material the percentage of Pt^{198} [parent of Ir^{196} in the (d,α) reaction] was increased from the normal 7.2% to 60.95% while the isotope Pt^{194} (parent of Ir^{192}) was reduced from the normal 32.8% to 3.57%. Thus the principal interfering iridium activity, the 75-day Ir^{192}, was reduced by almost a factor of 100 by using the enriched target material.

Decay curves were taken on 4π β-ray counters and γ-ray scintillation counters. Beta-spectral information was obtained using a 180° magnetic spectrometer,[4] as well as from aluminum absorption curves. Gamma radiations were examined with the γ-ray spectrometer and coincidence apparatus described previously.[5]

III. NATURAL PLATINUM BOMBARDMENTS

Using stacks of two and three platinum foils separated by copper absorbers of appropriate thicknesses, a total of seven platinum targets were bombarded by deuterons at various energies ranging from 9.6 to 20.4 Mev at the Argonne National Laboratory cyclotron. The decay curves of eight separate samples obtained at various bombarding energies showed the presence of only three components, with half-lives of 19 hours, ~ 8 days, and 75 days. Beta and γ-ray measurements showed that the 19-hr activity is due to Ir^{194}, while the 75-day activity comes from Ir^{192}. A half-life of 8.3 ± 0.5 days was obtained for the intermediate activity by averaging the values from eight curves. This may be compared with the value of ~ 9 days found by Butement and Poe.

TABLE I. Cross sections in barns for the (d,α) reaction on platinum.

Energy of deuterons in Mev	Target nuclei Pt^{194}	Pt^{196}
9.6 ± 1.3	$(1.2 \pm 0.4) \times 10^{-5}$	$(1.4 \pm 0.6) \times 10^{-4}$
11.3 ± 1.6	$(1.1 \pm 0.5) \times 10^{-4}$	$(3.3 \pm 1.6) \times 10^{-4}$
15.9 ± 1.5	$(1.7 \pm 0.8) \times 10^{-4}$	
19.2 ± 1.6	$(3.8 \pm 1.2) \times 10^{-4}$	$(4.4 \pm 1.5) \times 10^{-4}$
20.4 ± 0.8	$(2.3 \pm 1.0) \times 10^{-4}$	$(2.0 \pm 0.8) \times 10^{-4}$

The presence of only three half-lives indicates that the chemical separation was adequate, and that the 8.3-day activity was indeed due to iridium as claimed by Butement. This was further confirmed by the fact that repeating the chemical separation did not change the ratio of the three activities. Finally, the relative reaction cross-section values for the 8.3-day activity obtained on four different samples at bombardment energies of 19.2 and 20.4 Mev were all equal to within experimental error.

Rough cross section values for the (d,α) reaction on Pt^{194} and Pt^{196} to produce Ir^{192} (75-day) and Ir^{194} (19-hour) are given in Table I. The errors are estimated standard deviations. No corrections were made for the self-absorption of the β rays in their sources. The values at 20.4 Mev are the means of three observations for each isotope.

Beta spectral information[6] taken at several times after the end of bombardment is in accord with the literature values for Ir^{192} and Ir^{194} which emit β rays with maximum energies of 0.72 and 2.2 Mev, respectively, and with Butement's observation of an ~ 0.08-Mev β ray ascribed to Ir^{196}.

Aluminum absorption curve data substantiated the above spectrometer data. By following the decay of a portion of the β-ray spectrum at about 0.05 Mev it was found that the lowest energy group was decaying with a half-life of $\sim 10 \pm 2$ days. The decay was not followed long enough to define the half-life more exactly.

Gamma-ray spectrometer data[6] showed the presence of several γ rays which could not be ascribed to either Ir^{192} or Ir^{194}, although the large background due to Ir^{192} made measurements difficult. Coincidence data also proved inconclusive, again due to the interference from Ir^{192}.

In general though, the above results correlate well with those obtained by Butement and Poe who ascribed the 8.3-day activity to Ir^{196}. In hopes of obtaining more accurate information that would allow a decay scheme

[4] Meinke, Cassatt, and Hall, Atomic Energy Commission Report AECU-2944 June, 1954 (unpublished).
[5] W. A. Cassatt and W. W. Meinke, Phys. Rev. **99**, 760 (1955).
[6] A more complete record and exposition of experimental data can be found in D. G. Gardner, Ph.D. thesis, University of Michigan, 1957 (unpublished); also in Atomic Energy Commission Report AECU-3514 May, 1957 (unpublished).

to be formulated, it was decided to bombard a sample of enriched Pt^{198} to reduce the interference caused by Ir^{192}.

IV. ENRICHED PLATINUM BOMBARDMENT

Fifty mg of the powered platinum metal were bombarded with 23.5-Mev deuterons in the University of California 60-in. cyclotron. Six days after bombardment the sample was worked up and a decay curve started. Only a relatively small amount of activity was found in the iridium fraction after bombardment. Gamma-ray data showed that the primary activity was still Ir^{192}, with the addition of a small amount of γ radiation in the 0.7–0.9 Mev range. A large amount of γ-γ coincidence information was obtained, but all of it could be explained by the presence of Ir^{192}, whose decay has been studied extensively.[7]

The decay curves for this bombardment were followed for about 50 days. When resolved they showed only two activities to be present, the 75-day Ir^{192} and a small amount of a 3–4 day activity which probably was a mixture of Au^{196} and Au^{199}. No indication of an 8.3-day activity was found.

V. CONCLUSIONS

While the natural platinum bombardments strongly supported Butement and Poe in their assignment of the 8.3-day activity to Ir^{196}, the enriched isotope bombardment completely disqualified this assignment. The results of this work, however, indicate that the 8.3-day activity does belong to some isotope of iridium.

The following reinterpretation of the data can be made. The presence of a relatively large amount of platinum x-rays indicates that the 8.3-day activity decays primarily by electron capture, since little or no positron emission was indicated by the β-ray spectrometer data. This assumption allows the assignment of the $\sim$0.08-Mev β particles to fluorescent electrons, or conversion electrons from a low-energy γ ray. Hence the difficulty of demanding that the β decay be allowed, as would be necessary if $E_{max} \approx 0.08$ Mev and the half-life were $\sim$8 days, would be removed.

Decay by electron capture requires that the iridium activity be on the neutron deficient side of stability. Here Ir^{189} and Ir^{190} appear as possibilities, since each has an isomer with a half-life of the right order of magnitude. Neither of these isotopes has been completely characterized, but Aten and co-workers[8] have presented some information on Ir^{190}, Smith and Hollander[9] have reported on Ir^{189}, and Diamond and Hollander[2] recently list unpublished information on both Ir^{189} and Ir^{190}.

The γ rays found in this work correlate quite well with those reported by the above workers and permit the assumption that the observed 8.3-day activity is the result of the presence of both Ir^{189} and Ir^{190}. Ir^{189} could not be obtained by the (d,α) reaction on platinum, and Ir^{190} would have to come from Pt^{192} with a natural isotopic abundance of 0.78%. Furthermore Ir^{190} has a 3-hour isomer which would further reduce the amount of 8.3-day activity. In the enriched platinum target Pt^{192} was reduced to 0.042%, almost a factor of 100 less than Pt^{194} which produces the 75-day Ir^{192} activity. It is quite understandable that in the enriched isotopes bombardment no 8.3-day activity was found.

Neither Ir^{189} nor Ir^{190} can be produced by the (d,p) reaction on iridium. Therefore, to account for the 8.3-day activity found in the natural platinum bombardments, it is suggested that a small amount of osmium impurity was in the platinum targets. This would produce iridium activities by the favorable (d,n) reaction. Hence both Ir^{189} and Ir^{190} could be produced from Os^{188} and Os^{189} with natural abundances of 13.3% and 16.1%, respectively. Os^{190}(26.4%) and Os^{192}(41.0%) both yield stable iridium isotopes. Os^{186}(1.6%) would produce a small amount of the 12-hour Ir^{187} which would be difficult to resolve from the much more intense 19-hour Ir^{194}. Os^{187}(1.6%) would yield some 41-hour Ir^{188}, which would be masked to a certain extent by the Ir^{189} and Ir^{190} activities.

A re-examination of the decay curves did indicate that a small amount of the 41-hour Ir^{188} might have been present. Since the (d,n) reaction is more favorable than the (d,α) reaction by a factor of 10^2-10^3, the amount of osmium impurity needed to account for the results would only be 0.01 to 0.1%.

Concerning the true Ir^{196} activity, the present work suggests that an upper limit for the half-life would be about 5 hours. Actually, a much shorter half-life would be anticipated, perhaps in the range of minutes.

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[7] M. W. Johns and W. V. Nablo, Phys. Rev. **96**, 1599 (1954).
[8] Aten, DeFeyfer, Sterk, and Wapstra, Physica **21**, 740 (1955).
[9] W. G. Smith and J. M. Hollander, Phys. Rev. **98**, 1258 (1955).